CLAIMS

1. A method for surface measurement comprising the steps of :

(a) providing a specimen having a surface to be measured, said surface having a mean surface plane defined therefor;

(b) supporting a reference grating at a distance δ_T from said mean surface plane and substantially parallel to said mean surface plane, said distance δ_T being a Talbot distance, said reference grating having a pitch;

(c) causing a first beam of light to be directed through said reference grating onto said surface to be measured, said first beam of light having a wavelength λ and casting a first reference grating shadow onto said surface to be measured, said first reference grating shadow forming a first effective specimen grating; and

(d) detecting moire fringes produced by said reference grating and said first effective specimen grating due to variations in depth of said surface to be measured, said moire fringes being indicative of a condition of said surface to be measured;

wherein, in step (b), said Talbot distance δ_T is given by the formula:

$$\delta_T = n(2p^2/\lambda)$$

where: $n = 1, 2, \ldots$ is a positive integer,

p is said pitch of said reference grating, and

λ is said given wavelength of said first beam of light.

2. The method of Claim 1, wherein step (a) comprises providing a substrate wafer as said specimen.

3. The method of Claim 2, wherein in step (c), said first beam of light is coherent, further comprising the additional step of providing a source of coherent light which is spaced at a distance L from said reference grating and which

provides said coherent beam of light at a projection angle α formed with a normal to said grating.

4. The method of Claim 3, wherein in step (d), said detecting of said moire fringes is accomplished with an electronic camera, further comprising the additional step of locating said electronic camera at said distance L from said reference grating and at a distance D from said source of coherent light such that a line passing between said electronic camera and said source of coherent light is substantially parallel to said reference grating, said electronic camera being positioned to detect said moire fringes at a receiving angle β with respect to said normal to said grating, and wherein in step (d) said condition of said surface to be measured is determined using the formula:

$$w = NpL/D = Np/(\tan\alpha + \tan\beta)$$

where: w is said depth of said surface to be measured,
N is order of a given one of said moire fringes, and
$D >> Np$.

5. The method of Claim 4, further comprising the additional steps of:

providing a specimen plane on which said electronic wafer rests, said specimen plane being substantially parallel to said reference grating;

locating a smooth calibration specimen of substantially uniform thickness on said specimen plane;

viewing moire fringes formed on said smooth calibration specimen to detect any angle between said specimen plane and said reference grating; and

compensating for said angle in determining said depth w.

6. The method of Claim 5, further comprising the additional step of digitizing position and order of said moire fringes and entering said position and

order into a computer; wherein calculation of said depth w and compensation for said angle in determining w are also performed by said computer.

7. The method of Claim 6, wherein said order of said moire fringes is determined using an interpolation method.

8. The method of Claim 6, further comprising the additional steps of:

(e) repeating steps (b) through (d) for an opposite side surface of said specimen;

(f) identifying a point of known thickness for said specimen;

(g) using steps (e) and (f) to determine thickness of all points of said specimen from said depth w; and

(h) determining at least one of warpage and thickness variation from said thickness of all said points.

9. The method of Claim 2, wherein:

step (c) includes causing said first beam of light to illuminate substantially all of said surface to be measured; and

step (d) includes detecting said moire fringes for substantially all of said surface to be measured substantially simultaneously.

10. The method of Claim 9, wherein in step (d) said detecting is carried out with a camera.

11. The method of Claim 9 wherein in step (d) said detecting is carried out by visual observation.

12. The method of Claim 2, further comprising the additional step of adjusting said Talbot distance δ_T to measure different ranges of surface depths and variations.

13. The method of Claim 12, wherein said adjusting includes varying said Talbot distance δ_T via feedback based said moire fringes.

14. The method of Claim 2, further comprising the additional steps of:

causing a second beam of light to be directed through said reference grating onto said surface to be measured, said second beam of light having said wavelength λ and casting a second reference grating shadow onto said surface to be measured, said second reference grating shadow forming a second effective specimen grating, said second beam of light being phase-shifted with respect to said first beam of light;

detecting moire fringes produced by said reference grating and said second effective specimen grating due to said variation in depth of said surface to be measured, said moire fringes being indicative of said condition of said surface to be measured; and

using said moire fringes produced by said reference grating and said second effective specimen grating to determine information about said condition of said surface in between said moire fringes detected in step (d).

15. An apparatus for surface measurement of a specimen having a surface to be measured, the surface having by a mean surface plane defined therefor, said apparatus comprising:

(a) a specimen mount which is adapted to receive the specimen;

(b) a reference grating which is mounted adjacent said specimen mount and which is positioned to be substantially parallel to the mean

surface plane of the specimen when the specimen is received in said specimen mount, said reference grating and said specimen mount being movable with respect to each other so as to vary a distance δ_T between said reference grating and the mean surface plane of the specimen, said reference grating having a pitch;

(c) a light source which is mounted to direct a first beam of light having a given wavelength through said reference grating onto the surface to be measured when the specimen is received in said specimen mount, said first beam of light casting a first reference grating shadow onto the surface to be measured, said first reference grating shadow forming a first effective specimen grating; and

(d) a detector which is positioned to detect moire fringes produced by said reference grating and said first effective specimen grating due to variation in depth of the surface to be measured, said moire fringes being indicative of a condition of the surface to be measured;

wherein said distance δ_T is selected to be a Talbot distance given by the formula:

$$\delta_T = n(2p^2/\lambda)$$

where: $n = 1, 2, \ldots$ is a positive integer,

p is said pitch of said reference grating, and

λ is said given wavelength of said first beam of light.

16. The apparatus of Claim 15, further comprising a specimen having a surface to be measured which is received in said specimen mount, said surface to be measured having a mean surface plane defined therefor.

17. The apparatus of Claim 16, wherein said specimen is a substrate wafer to be used for fabrication of microelectronic devices and said specimen mount includes a specimen plane which is substantially parallel to said reference grating.

18. The apparatus of Claim 17, wherein:

said light source is a coherent light source and said first beam of light is a coherent beam of light; and

said light source is spaced a distance L from said reference grating and provides said first coherent beam of light at a projection angle α formed with respect to a normal to said grating.

19. The apparatus of Claim 18, wherein:

said detector is a camera;

said camera is located at said distance L from said reference grating and a distance D from said source of coherent light such that a line passing between said camera and said source of coherent light is substantially parallel to said reference grating;

said camera is positioned to detect said moire fringes at a receiving angle β formed with said normal to said grating; and

said condition of said surface to be measured is determined using the formula:

$$w = NpL/D = Np/(\tan\alpha + \tan\beta)$$

where: w is said depth of said surface to be measured,
N is order of a given one of said moire fringes, and
$D \gg Np$.

20. The apparatus of Claim 19, further comprising:

a digitizer which digitizes position and order of said moire fringes and which produces a signal characteristic of said position and order; and

a computer which receives said signal from said digitizer and calculates said depth w, and which compensates for angles between said specimen plane and said reference grating in determining w.

21. The apparatus of Claim 20, further comprising:

an interpolator which determines said order of said moire fringes using an interpolation method.

22. The apparatus of Claim 21, wherein said computer is configured to control movement of said reference grating with respect to said specimen mount, so as to adjust said Talbot distance δ_T to measure different ranges of surface depths and variations.

23. The apparatus of Claim 22, wherein said Talbot distance δ_T is adjusted by said computer via feedback based on said moire fringes.

24. The apparatus of Claim 19, wherein at least one of said distance L and said distance D is adjustable to permit said light source to produce a second beam of light which is phase-shifted with respect to said first beam of light for purposes of producing an additional set of said moire fringes which reveal additional information about said surface to be measured.